

Interfacial Dynamics of Colloidal Particles in Electrokinetically Driven Flows Measured by Multilayer Nano-Particle Image Velocimetry (MnPIV)

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1. Motivation

- Understanding interfacial transport important at microscale because of greater importance of surface effects: applications such as “Lab-on-a-Chip” devices
- Use multilayer nano-particle image velocimetry (MnPIV) to study electrokinetically driven flows
- Determine how external electric field E affect near-wall particle dynamics, distribution, and accuracy of interfacial PIV measurements

2. Introduction

- Electrokinetically driven flow: particle velocities due to electroosmotic flow + electrophoresis $\Rightarrow u_p = u_{EOF} + u_{EP}$
- Determine fluid velocities by measuring displacements of $O(10^5)$ fluorescent polystyrene particles
- Particles at $z \leq 400$ nm illuminated by evanescent waves from total internal reflection at wall-fluid interface
- Evanescent wave intensity $I(z) = I_0 \exp(-z/z_0) \Rightarrow$ directly estimate particle z positions

2. Experimental Details

- Steady flow: $E = 11\text{--}67$ V/cm
- Working fluid: 1 mM $\text{Na}_2\text{B}_4\text{O}_7$ (pH9.0, conductivity $165 \mu\text{S/cm}$) \Rightarrow thin EDL (Debye length = 6.8 nm)
- Characterize particles [radius a , ζ -potential ζ_p] by light scattering
 - $a = 54 \pm 7.3$ nm ($\zeta_p = -53 \pm 5.6$ mV)
 - $a = 238 \pm 22$ nm ($\zeta_p = -73 \pm 2.7$ mV)
- 1500 image pairs over 60 s ($\Delta t = 1.3\text{--}2.2$ ms; exp. 0.5 ms)
- $130 \mu\text{m} \times 36.6 \mu\text{m}$ images
- After locating particle centers by cross correlation, calculate area intensity of particle image, A_p
- Calculate particle edge-wall distance $h = z_p \ln(A_p^0/A_p)$, $A_p^0 =$ area intensity of particles at wall
- Errors in h are 4–17 nm
- Determine particle displacements using particle tracking

4. Results and Discussion

- Uniform flow with constant electroosmotic mobility $\mu_{eo} = 9.2 \times 10^{-4} \text{ cm}^2/\text{Vs} \Rightarrow \zeta_w = -132 \pm 10$ mV
- Tangential Brownian diffusion coefficients obtained from particle displacements \Rightarrow within 4% of Faxén
- Nonuniform near-wall particle distributions: particle depletion at $h < 50$ nm due to electrostatic and van der Waals effects (DLVO theory)
- For $a = 240$ nm, particles repelled from wall with increasing $E \Rightarrow$ nonuniform electric field in particle-wall gap leads to dielectrophoresis and induced-charge electroosmosis

5. Summary

- MnPIV used to study fully developed electrokinetically driven flow
- Electroosmotic velocities with uniform profile after accounting for particle electrophoresis $\Rightarrow \zeta_w = -132 \pm 10$ mV
- Tangential diffusion coefficients within 4% of Faxén predictions
- Near-wall particle distributions in agreement (w/in experimental error) with DLVO theory
- For $a = 240$ nm, $E > 22$ V/cm, additional repulsive force (due to nonuniform electric field in particle-wall gap)

